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The SKV-1 Stereocomparator

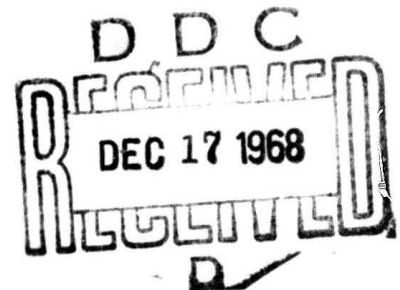
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THE SKV-1 STEREOCOMPARATOR

By

V. D. Derviz

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THE SKV-1 STEREOCOMPARATOR

V. D. Derviz

GEODEZIYA I KARTOGRAFIYA
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No. 1, 1968, pp. 37-49

At the TsNIIGAIK (Central Scientific Research Institute of Geodesy, Aerial Mapping and Cartography) the SKV-1 highly precise stereocomparator* was developed by the author of this article and has been produced at the EOMZ (Unified Optical-Mechanical Plant).

In developing the SKV-1 the objective was to obtain the greatest convenience and a high accuracy in performing all processes involved in making measurements from aerial photographs for constructing spatial photogrammetric nets**. This determined the schematic diagram for the SKV-1 and the need for developing a number of special devices. The following are the principal characteristics of the instrument.

1. Each aerial photograph can be independently moved along the two coordinate axes with the most complete adherence to the precise measurements principle (Abbe Principle) with a fixed optical system.
2. For each coordinate motion there is an automatic readout system with a graduation to $1.25\mu\text{m}$, plotted on metrological diffraction gratings.
3. The measured moving coordinates are readable from a light-up signal panel and are automatically registered in a form convenient for digital input into an electronic computer.
4. A binocular optical system with a magnification 8 to $20\times$. This ensures a precise stereoscopic and monocular pointing, switching of the sighting axes and turning of the image.

* Author's Certificate No. 190 592 for this invention was awarded to V. D. Derviz, M. D. Konshin, V. G. Afremov, Ye. T. Zdobnikov, G. A. Zotov and V. K. Orlov.

** The results of development of the requirements on measurement accuracy are presented in an article by V. D. Derviz, "The Accuracy of a Stereocomparator for the Analytical Method of Spatial Phototriangulation," published in Geodeziya i Kartografiya, No. 2, 1965.

5. The carriages are supplied with electrical drives which have rapid and slow rates of motion.

6. There is precise stereoscopic identification of triple-overlap points using the method of repeated pointing by setting the carriages by readings.

7. The instrument has a photorecorder for photographing an observed point on which the measuring dot is set and also a projecting device. These devices are used in the stereoscopic identification of points in adjacent flight lines.

Description and Technical Specifications of the Instrument

Figure 1 shows the general appearance and Fig. 2 the schematic diagram of the SKV-1. The frame 1 carries two devices for measuring coordinates. These are identical in design. The base plates 2 and 3 of the coordinate-measuring devices have Y-guides 5 and 6 along which the Y-carriage 4 moves. On the Y-carriage there are guides 8 and 9 along which the X-carriage 10 moves. The X-carriages have removable frames 11 for aerial photographs (measuring 18 x 18 cm) which can be rotated in their plane by an angle $\pm 5^\circ$ by remote control from the front panel of the instrument.

The distances of movement are measured using pairs of metrological diffraction gratings*. The long reflecting diffraction gratings - measuring rules of these pairs are in the same horizontal plane as the photographs and at the same time on the extensions of the X-axis 16 and Y-axis 15. As a result, in this instrument there is rigorous adherence to the precise measurements principle (Abbe principle) during measurement of the Y-coordinates. With respect to the X-coordinates there is some departure from rigorous adherence to this principle by a minimum value equal to the Y-coordinate of the observed point. This design reduces coordinate measurement errors to a minimum.

The dimensions of the instrument in the direction of the X-, Y- and H-axes are 2.2 x 1.25 x 1.34 m respectively ($H_{\max} = 1.5$ m); the weight without the electronic readout units is ~ 1000 kg.

Optical system. The branches of the fixed binocular system 13 are moved toward the aerial photographs from below

* The metrological reflecting diffraction gratings were developed at the State Optical Institute by F. M. Gerasimov, G. N. Rassudova, and V. P. Sergeyev; Author's Certificate No. 140 598.

and extend from the front of the instrument in the eyepieces 12. The photographs are illuminated from the top of the instrument. System magnification of $8\times$, $16\times$, or $20\times$ is set by changing the eyepieces. The corresponding diameters of the fields of view will be 15, 9 and 7 mm. The observing system has switching of the sighting axes and separate turning of the images by $\pm 180^\circ$ by means of a Dove prism. The round instrument dots are 35-40 μm in diameter; they are in vertical short optical branches situated on the base plates 2 and 3 of the devices for measuring coordinates and near the photographs. This makes it possible to obtain extremely stable measurements results. In addition to the dots used for stereoscopic measurements there are marks in the form of pairs of angle bisectors (Fig. 3) arranged at an angle, 90° to one another. These are used for precise readings on the centers of the images of the crosses.

Design of diffraction unit for measuring linear movements used in automatic coordinate readout (see Fig. 4). The optical system creates a parallel beam of rays incident on the measuring gratings: small 18 and large 15 and 16. The small grating has four fields of lines with a 90° phase shift. This makes it possible to obtain a modulated light flux through the wedges 36 and 37 during movement of the gratings. From each grating field the light is incident on an individual photocell. The phase difference in the light fluxes is constant but the amplitudes are independent (within certain limits) of the rotation of the small grating relative to the large one. As a result, at the time of each relative motion of the gratings by 1.25 μm the optical system generates a current pulse. This structural design makes possible full exploitation of the advantages of a construction with precise adherence to the Abbe principle and makes the instrument little sensitive to maintenance of the linearity of the guides. The measurement accuracy therefore remains stable over a long period.

The system for converting linear movement into a digital code converts the signals into current pulses, performs an algebraic count of the pulses fed each 1.25 μm movement of the carriages and stores this information.

The digital indication of the moving coordinates x_{left} , x_{right} , y_{left} , y_{right} is on a panel which lights up. Between the moving coordinate rows are the memory rows in which the values of the coordinates of the triple-overlap tie-in points are registered by moving the levers situated at the bottom of the front panel between the motion wheels (see Fig. 1). The memory rows serve for precise repeated setting of coordinates from readings for stereoscopic identification of the points in the flight line.

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Figure 1.

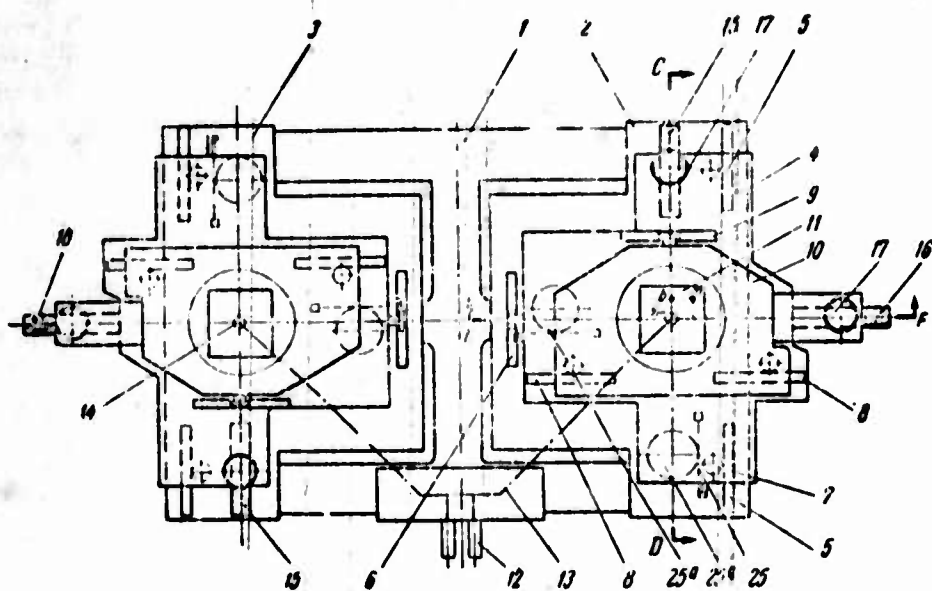


Figure 2.

The readings are registered on a paper tape 210 mm wide by teletype. Three programs are used in the printout: 1) the number of the point and four coordinates; 2) number of the point and the coordinates of the left photograph; 3) number of the point and coordinates of the right photograph. Depending on the position of the sighting axes switch, the coordinates of the left photograph are printed out first and then the right coordinates or vice versa. Three readout buttons on the instrument panel are duplicated by readout foot pedals.

The readings are punched on tape for direct input of the results into an electronic computer.

Devices for stereoscopic identification of points on adjacent flight lines. The tie-in points for the overlap between flight lines with the pointed dot are photographed simultaneously with the reading. The easily removable magazines hold 36 frames 22 mm in diameter. On a frame the points are marked with a number consisting of five digits. The processed film is inserted into a projector (to the right of the eyepiece system). The image of the phototrace is optically introduced into the right or left eyepiece of the observing system. The points are stereoscopically identified using a Dove prism for eliminating vertical parallax.

System for moving aerial photographs. The instrument carriages are moved by means of selsyn systems through reducers and disks 25a (see Fig. 2) with two steel ribbons 25 whose ends are attached to the carriages. The carriages are moved in the X- and Y-directions at the same time by using the outer wheels on the front panel (see Fig. 1). The middle wheels are used for differential motions ΔX and ΔY . The motions can be made in two ranges at rates of 5 or 0.5 mm per turn of the wheel.

Differential motions can be made simultaneously with joint motions. Above the middle wheels there are levers for making joint motions in the X-direction and independently in the Y-direction from an electric drive. There are two speed ranges: from 0.3 to 1.5 mm/sec and from 1.5 to 8 mm/sec. There is a switch for introducing a positive or negative base manually or with an electric drive.

System for indicating places of measurements. A contact print measuring 18 x 18 cm is placed on the panel screen placed above the upper housing of the instrument (see Fig. 1). Indication of place of measurement is synchronized with the motion of the left instrument carriage. On the screen (print) a light dot appears, together with a concentric circle 10 mm in diameter indicating the place of measurements with an accuracy to ± 3 mm. The device makes possible rapid approximate pointing on the necessary points without looking

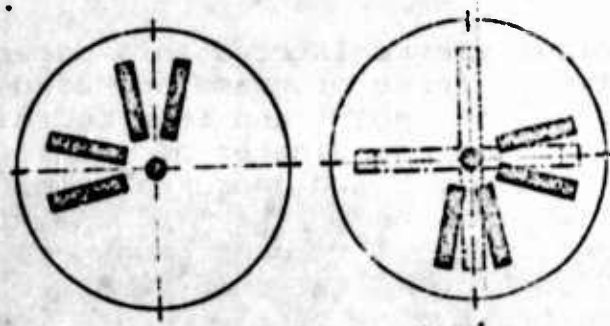


Figure 3.

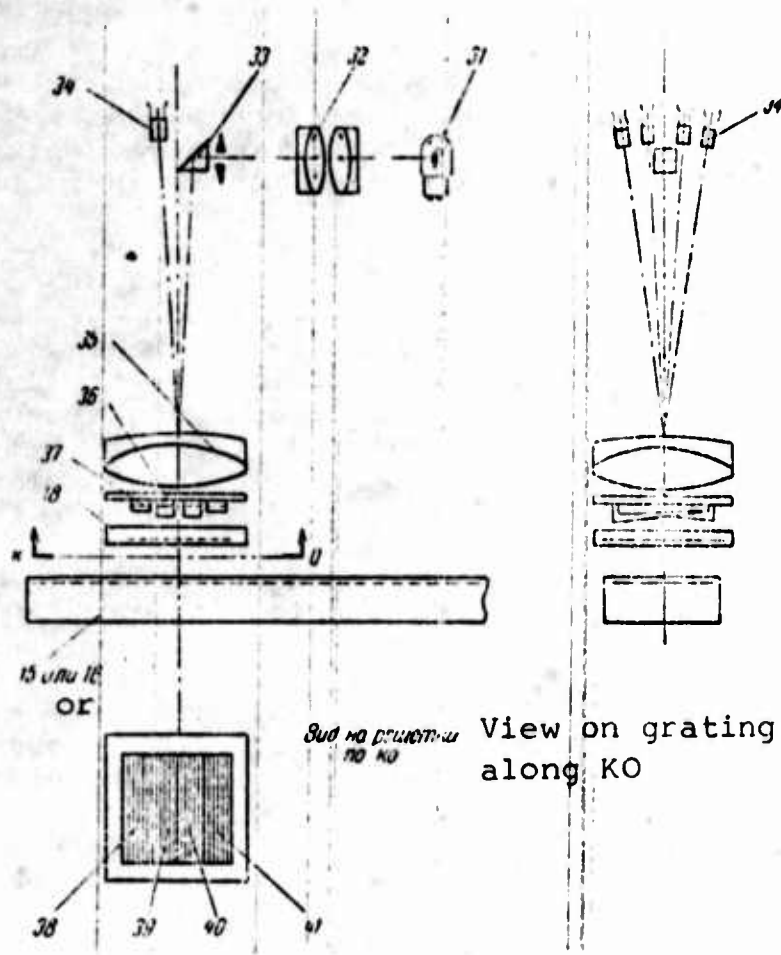


Figure 4.

in the binocular system.

Characteristics of Processing of Aerial Photographs

1. The diapositives are approximately centered. The aerial photographs are oriented using the images of the crosses (fiducial marks) plotted on the aerial camera smoothing glass.

2. The position of the points on the aerial photograph is determined by measurements of segments -- the coordinate increments from the nearest images of the crosses. The position of the crosses is compared in advance and the effect of aerial film distortions therefore is taken into account. The vertical parallaxes are measured by turning the images of the Dove prisms by 90° .

3. The coordinates of the triple overlap points are transferred to the next stereopair of the flight line from the readings using the memory rows on the light-up panel, making it possible to compare the repeatedly set coordinates with the readings on the panel (the earlier measured coordinates of the second photograph of the preceding stereopair). Photoregistry of these points is possible for subsequent identification of photogrammetric extension points during relief sketching.

4. The tie-in points of adjacent flight lines with the dot pointed on them must be photographed at the time when coordinates are read. Stereoscopic identification of points from the phototrace is used in processing adjacent flight lines.

Investigation of SKV-1 Instrument Accuracy

Test method. The instrument accuracy of the stereo-comparators is determined by measurements of reliably compared reference gratings. After excluding the systematic errors the residual errors characterize the accuracy in coordinate determination.

We will examine Fig. 5, where the following notations are used:

$X_{\text{right } 0}, Y_{\text{right } 0}$, is the rectangular coordinate system of an "ideal instrument;" $X_{\text{right}}, Y_{\text{right}}$ is the coordinate system of the real SKV-1 instrument, differing from the coordinate system of the ideal instrument in the nonperpendicularity of the $d\theta$ axes and the presence of the scale factors dm_x, dm_y of the scales; $X_{\text{dis}}, Y_{\text{dis}}$, is the coordinate system of the reference grating which during orientation

experiences a displacement relative to the coordinate system of the real instrument by the values dX_0 , dY_0 and rotation $d\alpha_x$; X_0' , Y_0' is an intermediate coordinate system whose axes are parallel to the axes of the X_{dis} , Y_{dis} system of the reference grating.

The reading scales are situated on the extension of the axes X_{right} 0, Y_{right} 0, intersecting at the point 0, which is a projection of the dot of the optical system onto the plane of the photograph holder in the zero position of the reading system. The guides are linear.

We will write the differences between the true and the measured values of the coordinates of the m point of the grating

$$\Delta X = X_C - X_\pi; \quad \Delta Y = Y_C - Y_\pi \quad (1)$$

$$c = dis \quad \pi = right$$

We will express the coordinates X_{right} and Y_{right} through the unknown elements of orientation of the grating for a real instrument containing the errors dm_x , dm_y , $d\beta$ and the known coordinates X_{dis} , Y_{dis} . After rectifications and exclusion of second-order values we obtain

$$\left. \begin{aligned} dX &= dX_0 - X_C dm_x - Y_C d\alpha_y; \\ dY &= dY_0 - Y_C dm_y + X_C d\alpha_x; \end{aligned} \right\} \quad (2)$$

$$c = dis$$

The error equations assume the form

$$\left. \begin{aligned} v_x &= dX_0 - X_C dm_x - Y_C d\alpha_y - dX; \\ v_y &= dY_0 - Y_C dm_y + X_C d\alpha_x - dY; \end{aligned} \right\} \quad (3)$$

$$c = dis$$

By solving the first and second equations (3) separately under the condition $[v_x v_x] = \min$ and $[v_y v_y] = \min$, in accordance with the proposal made by Ye. V. Fillimonov, we obtain the values of the systematic errors

$$\left. \begin{aligned} dX_0 &= -\frac{[dX]}{n}; & dY_0 &= -\frac{[dY]}{n}; \\ dm_x &= -\frac{[XdX]}{[X^2]}; & dm_y &= -\frac{[YdY]}{[Y^2]}; \\ d\alpha_y &= -\frac{[YdX]}{[Y^2]}; & d\alpha_x &= -\frac{[XdY]}{[X^2]}. \end{aligned} \right\} \quad (4)$$

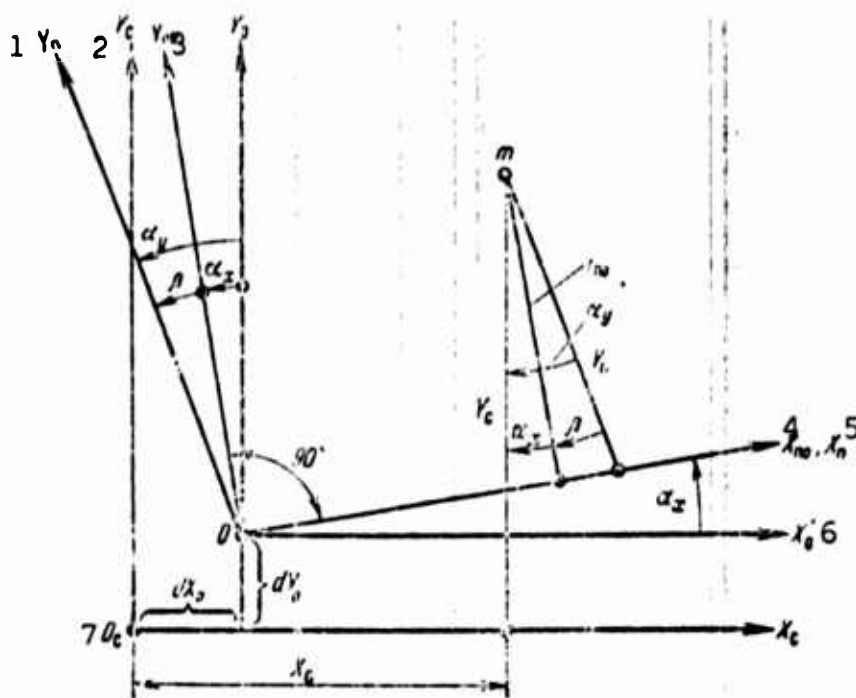


Рис. 5

Figure 5.

- Key:
- 1- Y_n = right;
 - 2- Y_c = dis;
 - 3- Y_{no} = right o;
 - 4- X_{no} = right o;
 - 5- X_n = right;
 - 6- X_c = dis;
 - 7- O_c = dis.

The nonperpendicularity of the axes for each carriage is found as the difference

$$d\alpha_y - d\alpha_x = d\beta$$

with the mean square error

$$m_{d\beta} = \pm \sqrt{\frac{m_y^2}{[Y^2]} + \frac{m_x^2}{[X^2]}}. \quad (5)$$

The mean square errors in determining coordinates will be

$$m_x = \pm \sqrt{\frac{[v_x v_x]}{n-r}}; \quad m_y = \pm \sqrt{\frac{[v_y v_y]}{n-r}}, \quad (6)$$

where n is the number of points at which measurements are made; r is the number of degrees of freedom, equal to three.

The accuracy in the mean square errors in determining coordinates was estimated using the formulas

$$m_{m_x} = \pm \sqrt{\frac{[v_x v_x]}{2(n-r)}}; \quad m_{m_y} = \pm \sqrt{\frac{[v_y v_y]}{2(n-r)}}. \quad (7)$$

The mean square error σ_0 in the horizontal position of points will be

$$\sigma_0 = \pm \sqrt{\frac{[v_x v_x] + [v_y v_y]}{n_1 - r_1}}, \quad (8)$$

where $n_1 = 50$; $r_1 = 6$.

For evaluating the accuracy in measuring segments (coordinate increments) 10 mm in length we write the differences $v_{x_{i+1}} - v_{x_i}$ and $v_{y_{i+1}} - v_{y_i}$ of the measured lengths of the segments between two adjacent rows of points.

The mean square errors in determining the lengths of the segments are computed using the formulas

$$m_{\Delta_x} = \pm \sqrt{\frac{[\delta v_x^2]}{k}}; \quad m_{\Delta_y} = \pm \sqrt{\frac{[\delta v_y^2]}{k}}, \quad (9)$$

where k is the number of independent segments; δv_x and δv_y are the deviations in the length of the measured segment from the true value.

The SKV stereocomparator was subjected to thorough long-term tests for the purpose of determining its measuring properties and possibilities for modification.

Yu. I. Smirnov played a major part in the investigations of this instrument.

1. Accuracy in stereoscopic and monocular pointings. The pointing error is a result of random instrument errors characterizing the accuracy of its optical, mechanical and readout components and systems transmitting and registering information. In addition, this error is dependent on the configuration, size and contrast of the objects which are sighted upon.

During measurements with each instrument carriage the mark is pointed on five points, one of which is situated in the center and four along the edges of a standard grating measuring 160 x 160 mm. Pointing on each point is repeated 20 times. The observation program was performed by different observers several times each.

No differences were discovered between the results of pointings on the edge and center of the grating with the right and left carriages and also along the X- and Y-axes. The mean square error m_{point} in one pointing along the X- and Y-axes for magnifications 20 \times and 16 \times falls in the range ± 0.9 to $1.0 \mu\text{m}$ both during monocular pointing with special marks in the form of angle bisectors and with a circular stereoscopic dot. The accuracy in monocular pointing with the angular bisectors (with $v = 8^\circ$) is characterized by a mean square error $m_{\text{point}} = \pm 1.4 \mu\text{m}$ on the reference grating and $m_{\text{point}} = \pm 1.5 \mu\text{m}$ on the image of the crosses, which is somewhat greater than the accuracy in stereoscopic pointing in which $m_{\text{point}} = \pm 1.6 \mu\text{m}$. This confirms the correctness of choice in design of the marks in the form of angle bisectors and also is of practical importance for measurements from aerial photographs with an image of crosses. The high accuracy in pointing on reference objects demonstrates that the random errors in the SKV-1 instrument are extremely small.

The accuracy in stereoscopic pointing during measurements from diapositives of aerial photographs is determined for the most part by the photographic quality of the image and varies in a rather broad range: from $\pm 6 \mu\text{m}$ on photographs of poor quality to $\pm 2.8 \mu\text{m}$ on photographs of good quality.

The accuracy in pointing when setting the coordinates from readings with subsequent stereoscopic identification in comparison with identification without supplementary means is increased by approximately 30%.

The use of phototraces with an image of the pointing points and instrument marks makes it possible to identify identical points in adjacent flight lines with errors of the same order of magnitude as the errors in stereoscopic pointing. The use of image rotation by means of Dove prisms for measuring the vertical parallaxes makes it possible to improve somewhat the accuracy in pointing the instrument mark. Investigations in this field are continuing.

2. Accuracy in coordinate measurement. The reference gratings were compared on an "Ascorecord" monocomparator of the "Karl Zeiss Jena" Peoples Enterprise. The mean square error in deviation of points of intersection of the reference gratings from the nominal values is $\pm 0.5 \mu\text{m}$.

On the SKV-1 stereocomparator the measurements were made at 25.81 and 145 points uniformly arranged on reference gratings measuring 180 x 180 mm. The observations were made with a magnification $V = 20\times$ during forward and reverse rotations with two monocular pointings on the point by the angular bisectors.

The measurements were made from 1 March to 10 April 1967 at an air temperature from +20 to +23°C. The temperature change during seven hours did not exceed 1.6°C; the relative humidity was 40 to 70%. The number of points was $n = 91$ and during measurements in series No. 6 was $n = 145$.

The measurement results were processed by the method described above.

Table 1.

Right Carriage

Standard Grating No. 278

№ п.п. a	Наблюдатель b.	$m_x, \mu\text{m}$ c	$m_y, \mu\text{m}$ c	Предельные ошибки, μm $\pm \sigma_x, \sigma_{\text{max}}$ $\pm \sigma_y, \sigma_{\text{max}}$ d	$\sigma, \mu\text{m}$ c	$d\sigma^\circ$	$(dm_x - dm_y) \times 10^{-5}$
1	A	$\pm 0,8$	$\pm 1,0$	$\frac{+2,3}{-2,6}$	$\pm 0,9$	+3,3	-1,5
2	B	1,0	1,2	$\frac{+3,1}{-2,7}$	1,1	+0,2	+0,2
3	C	0,7	1,1	$\frac{+2,2}{-2,5}$	1,0	-0,6	-1,7
4	A	0,9	0,8	$\frac{+1,8}{-1,8}$	0,9	+0,6	-0,7
5	A	1,1	1,0	$\frac{+2,1}{-2,5}$	1,0	-1,9	-2,0
6	A	1,1	1,0	$\frac{+3,5}{-3,9}$	1,0	+0,6	-2,4
7	F	0,9	1,3	$\frac{+2,9}{-2,5}$	1,1	+3,4	-2,2
Среднее e		$\pm 0,9$	$\pm 1,1$		$\pm 1,0$	+0,8	-1,5

Key: a- No.; b- Observer; c- μm ; d- Limiting errors, μm ; e- Mean.

According to the data in Tables 1 and 2 the mean square

errors m_x and m_y in determining coordinates vary in the range from ± 0.7 to $\pm 1.4 \mu\text{m}$. The mean square error in the position of a point was $\sigma_0 = \pm 1.0 \mu\text{m}$. The maximum residual coordinate errors $v_{x\text{max}}$ and $v_{y\text{max}}$ do not exceed $3.9 \mu\text{m}$.

The mean values of the angles $d\beta$ of nonperpendicularity of the axes for the right carriage are $d\beta_{\text{right}} = \pm 0''.8$ and for the left carriage $d\beta_{\text{left}} = \pm 0''.1$; the deviations in the individual determinations do not exceed $2''.7$ of the mean values, which when $x = y = 80 \text{ mm}$ gives a maximum error of $1 \mu\text{m}$. The mean values $m_{m_x} = m_{m_y} = \pm 0.09 \mu\text{m}$; $m_{d\beta} = \pm 0''.7$.

Table 3 gives the results of SKV-1 tests made from May 1966 through February 1967 (from No. 1 through 8 inclusive the measurements were made in 1966). During the tests the air temperature was $18.6^\circ - 24^\circ\text{C}$.

Comparing the data in Table 3 with the results given in Tables 1 and 2 we see that in the 10.5-month period the instrument had a stable high measurement accuracy characterized by a mean square error $m_x = m_y = 1 \mu\text{m}$.

The accuracy in determining the length of 10-mm segments, computed from measurements at 145 points, is characterized by a mean square error $m_{\Delta l_x} = m_{\Delta l_y} = \pm 1.1 \mu\text{m}$.

The tests revealed that all the operations necessary during measurements for constructing a spatial photogrammetric net are performed simply on the SKV-1 and with adequate convenience for the operator.

The instrument accuracy, characterized by a mean square error $m_{x,y} = \pm (1.0 - 1.4) \mu\text{m}$, corresponds to the required accuracy.

Due to automation of a number of processes measurements with the SKV-1 are made approximately twice as fast as on existing stereocomparators.

The tests revealed the need for a number of improvements for further increasing the reliability of the electronic readout and recording components of the SKV-1; this will be taken into account during production of the next instrument models.

The high measurement accuracy in performing all operations with the SKV-1 will make it possible to use the most precise variant of the analytical method of spatial phototriangulation*.

* Konshin, M. D., "Present Status and Prospects for Improving the Analytical Method of Photogrammetric Extension," Geodeziya i Kartografiya, No. 8, 1966.

Table 2.

Left Carriage

Reference Grating No. 275

№ п.п.	Наблюдатель	$m_x, \text{мкм}$	$m_y, \text{мкм}$	Предельные ошибки, мкм $+v_x, y_{\text{max}}$ $-v_x, y_{\text{max}}$	$s, \text{мкм}$	d, μ	$(dm_x - dm_y) \cdot 10^{-2}$
a	b	c	c	d	c		
1	A	$\pm 0,8$	$\pm 1,0$	$\frac{+2,5}{-1,9}$	$\pm 1,0$	-1,7	-3,1
2	B	1,0	1,3	$\frac{+2,6}{-3,6}$	1,1	+0,2	+0,2
3	C	0,9	0,8	$\frac{+2,4}{-2,2}$	0,8	-1,5	-2,1
4	A	0,9	1,1	$\frac{+2,6}{-2,6}$	1,0	-1,2	-2,3
5	A	1,0	1,2	$\frac{+2,4}{-3,2}$	1,1	-1,8	-1,1
6	A	0,9	1,2	$\frac{+2,9}{-3,8}$	1,1	+2,0	-3,2
7	F	1,4	1,2	$\frac{+3,0}{-3,0}$	1,3	+2,8	-4,3
Среднее e		$\pm 1,0$	$\pm 1,1$		$\pm 1,0$	$\pm 0,1$	-2,8

Key: a- No.; b- Observer; c- μm ; d- Limiting errors;
e- Mean.

Table 3.

№ п.п. a	Дата b	Коли- чество точек c	d m_x мкм для кареток		d m_y мкм для кареток		d m_z мкм для кареток	
			e правой	f левой	e правой	f левой	e правой	f левой
1	28/V	25	±0,9	±0,8	±0,9	±1,0	±0,9	±0,9
2	1 и 11/VI	81	0,8	0,7	1,0	1,1	0,9	0,9
3	11 и 30/VIII	81	0,8	1,3	1,0	1,5	0,9	1,4
4	28/IX	25	0,8	1,0	1,2	1,3	1,1	1,2
5	29 и 30/IX	25	0,9	0,9	0,8	1,1	0,8	1,0
6	25/X	25	0,8	1,1	1,0	1,1	0,9	1,1
7	17/XI	25	0,9	1,5	1,1	1,1	1,0	1,4
8	6/XII	25	1,2	1,3	1,2	1,4	1,2	1,4
9	20/I	25	0,6	0,8	0,9	1,1	0,8	0,9
10	6/II	25	0,7	1,1	1,0	1,2	0,8	1,1
g Среднее			±0,8	±1,0	±1,0	±1,2	±0,9	±1,1

Key: a- No.;
b- Date;
c- Number of points;
d- m_x , μm for carriages;
e- right;
f- left;
g- mean.

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13. ABSTRACT Reasons for the development of the Russian SKV-1 stereocomparator are discussed in so far as they pertain to obtaining greatest convenience and accuracy in performing all processes involved in making measurements from aerial photographs for constructing spatial photogrammetric nets. The instrument is described, and its specifications are listed, as are the results of an investigation of the instrument's accuracy.			

14.

KEY WORDS

stereocomparator
photogrammetry
triangulation
metrology
diffraction grating
aerial photograph
geologic research facility
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